Ocean and Climate Change Institute

Annual Report Winter 2006

Message from the OCCI Director Terry Joyce

Photo by Dave Gray

The Ocean and Climate Change Institute (OCCI) seeks to advance knowledge about the ocean's interaction with Earth's climate system and to convey that information via scientific publications and public outreach. Like other Ocean Institutes at WHOI, we work across existing departmental structures without a permanent research staff. We have selected several interdisciplinary themes having to do with the role of ocean circulation in the global climate system, how changes in the global water cycle affect climate, how the ocean acts as a sink for atmospheric carbon dioxide, and what roles the North Atlantic and Arctic oceans play in abrupt climate change.

The three projects selected for this report reflect the breadth of work on the above issues. The first is a project led by Fiamma Straneo, of the Physical Oceanography Department, who seeks to obtain initial data on the flow of freshwater out of Hudson Strait into the North Atlantic. It is clear that the ocean component of Earth's climate regulation system in the North Atlantic Ocean has behaved irregularly in the past. The heat transport carried northward by the poleward-flowing, warm Gulf Stream/North Atlantic Current and the equator-ward flowing cold, Deep Western Boundary current far exceeds that of the comparable system in the North Pacific: the Kuroshio. The reason for this is the production and sinking of cold water in the northern reaches of the N. Atlantic. This does not occur in the N. Pacific, because the water there is too fresh to sink, even after it is cooled.

A disrupted circulation pattern has caused and may cause an abrupt change to a colder climate in the areas surrounding the N. Atlantic Ocean. In today's climate, the Labrador Sea is a key region where deep water is formed and where freshwater capping of the ocean surface could alter deep convection patterns. With Comer Science and Education Foundation support, Fiamma is examining one important pathway for freshwater to exit the Arctic and enter the Labrador Sea via Hudson Bay.

Olivier Marchal, of the Geology and Geophysics Department, is investigating some novel geochemical tracers, radioisotopes of thorium and protactinium. Thorium-230 and Protactinium-231, are produced by radioactive decay of uranium in seawater. Both isotopes quickly attach to falling particles in the ocean and ultimately settle on the seafloor. The rate at which they are taken up by particles is different, with ^{231}Pa remaining in the seawater longer by approximately 100-200 years. By comparing the ratio of these two tracers in sediments, one can make estimates of the residence time of the overlying waters in past eras and, hence, the flow rates. Olivier's project does not examine sediments themselves, but concentrations of these two tracers in the seawater, where they are present in dissolved and particulate forms. These data and some innovative ideas about combining them with traditional variables used in physical oceanography - temperature, salinity, and density - are testing the utility of this new method as an indicator of the present, not past, ocean flow. This project combines elements of geology, chemistry and physics, and is probably the most interdisciplinary project presently supported by the OCCI.

Scott Doney has been an OCCI Fellow for the past three years. His report deals with an important aspect of biology and climate change due to gradual acidification of seawater by increasing concentrations of anthropogenic CO_2. Many marine plants and animals that form shells out of calcium carbonate may soon have a more difficult time maintaining their shells in a future of increasing CO_2. As the ocean becomes more acidic, a variety of marine animals, including those dependent on coral reefs, face an uncertain future.

Further information about OCCI can be found on our Web site: http://www.whoi.edu/institutes/occi/index.htm. □

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www.whoi.edu/institutes/occi

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Ocean Circulation and Climate

Freshwater Input from Hudson Strait to the North Atlantic

Fiamma Straneo

Earth's climate is intimately linked to the global ocean circulation system, which is driven, in part, by the sinking of cold, dense water in the North Atlantic. As this cold water sinks, warmer water from the tropics is drawn up the Atlantic seaboard in the Gulf Stream, releasing heat as it journeys northward, then eastward toward Europe. This system has tempered the climate in the northeastern US and northern Europe for centuries.

Freshwater is one of the key players in this process; models show that even relatively small changes in the amount of freshwater flowing into the North Atlantic can result in large climate changes. Freshwater, which is less dense than warm salty water, tends to float on top of the saltwater, effectively capping it off and preventing the release of heat. When more freshwater is released into the North Atlantic, less heat is released to temper the region's climate.

Freshwater reaches the North Atlantic through three major pathways: (left to right arrows below) Hudson Strait (between the Hudson Bay drainage basin and the Labrador Sea), Davis Strait (between the Arctic Ocean and the Labrador Sea), and Fram Strait (between the Arctic Ocean and the Nordic Seas).

These straits act as bottlenecks, focusing the flow of freshwater into the North Atlantic. As such, they are ideal locations for measuring freshwater flow in the region. Since freshwater floats high in the water column, measurements that extend all the way to the surface are critical targets for freshwater monitoring. The convergence of sea-ice and icebergs in these tight passages, however, poses a serious challenge to year-round monitoring operations. Until recently, observations were limited to the deeper part of the flow to avoid instrument contact with ice and resulting equipment damage.

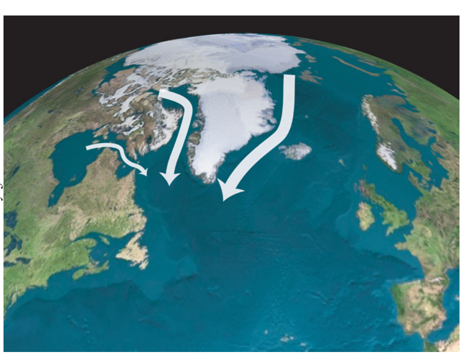


Illustration by Jack Cook

Three major pathways for freshwater to enter the North Atlantic. Left to right arrows: Hudson Strait, Davis Strait and Fram Strait.

In 2004, thanks to support from the Ocean and Climate Change Institute through a Comer Science and Education Foundation grant, a field program was initiated to monitor North Atlantic freshwater through Hudson Strait. This project found enthusiastic support from Canadian colleagues in Quebec, who agreed to help us deploy our instruments in the Strait, as well as to add some instruments of their own. Together we deployed a series of moorings across the southern portion of Hudson Strait, where the freshwater flows into the Labrador Sea.

WHOI engineers, Steve Liberatore and Dan Frye, developed an instrument to overcome the difficulties of working under the ice. This instrument, the Arctic Winch, is mounted on the top of a mooring several tens of meters below the sea-surface. Once a day, the winch allows a profiler full of sensors to rise to the surface to record water temperature and salinity. When the profiler reaches the ocean surface or the bottom of the sea ice, the winch rapidly pulls the profiler back down. This allows measurements to extend high in the water column – to the bottom of the sea-ice – without damaging the equipment.

After a year in Hudson Strait, the moorings and Arctic winch were recovered. The data show strong bursts of freshwater flowing through Hudson Strait. These are likely due to the input from rivers, sea-ice melt, and the inflow of Arctic freshwater. The profiler worked throughout its entire mission but, over time, found it increasingly hard to reach the surface. We surmise that this may have been due to strong currents in Hudson Strait causing mechanical wear on the instrument. With the data in hand, we will now be able to improve its performance. Generally, we were pleased to have such a success for a newly developed instrument; and, once we analyze all the data, for the first time we will have a true estimate of the freshwater contribution from the Hudson Bay system to the North Atlantic.

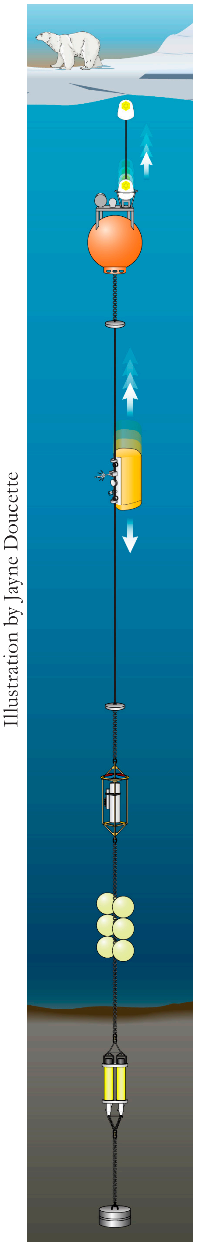


Illustration by Jayne Doucette

Mooring in Hudson Strait with Arctic Winch on top.

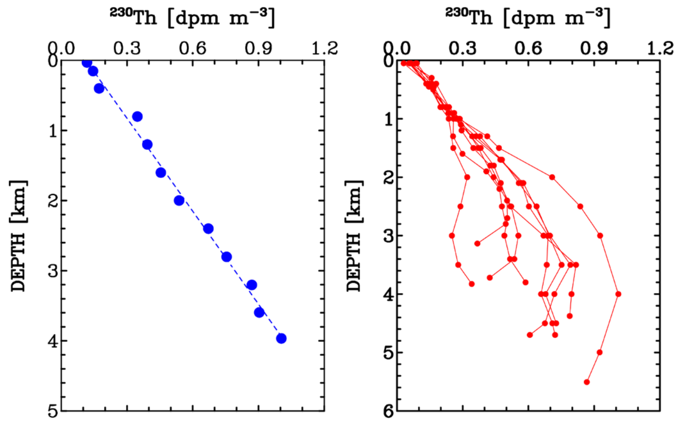
Arctic Winch on top of a buoy. Photo by Fiamma Straneo.

In September 2005, the moorings were re-deployed for a second year. Since observations in the rivers and sea-ice of Hudson Bay (as well as other parts of the Arctic) indicate that this region is changing rapidly, we are now working on a proposal to a federal agency to maintain this observing system for several more years. For more information on this project see *Oceanus*, magazine, vol. 44, no. 3, 2005. □

Paleoclimate Studies

Geochemical Tracers in the Deep Ocean

Olivier Marchal



Measurements of ^{230}Th in the ocean as a function of depth. Units are disintegration per minute per cubic meter of seawater (dpm m^{-3}).

[Left panel]: Data from a station in the subantarctic zone of the Southern Ocean. The distribution of thorium varies linearly with depth, providing strong support to the theory of a reversible exchange of thorium with sinking particles. [Right panel]: Several sets of measurements from the North Atlantic. All profiles show comparable thorium values in the top 1-1.5 km of the water column, which presumably reflects the dominant influence of the reversible exchange. They diverge below, owing most likely to the effect of the abyssal circulation. A first goal of our project is to understand this effect by combining this data with a circulation model. The data used in this project have been generated by American and European researchers. Many of these data, including this figure, were produced by Roger Francois, with whom Olivier is collaborating.

The general circulation of the ocean is a critical element of the climate system, as it transports heat from tropical to high latitudes. An important component of this circulation is the abyssal circulation, which takes place below a depth of about one kilometer. Although abyssal waters occupy about three quarters of the whole ocean volume, the abyssal circulation is notoriously problematic to study. The classical method, which relies on the distribution of seawater density to understand the strength of horizontal currents, is difficult to apply in the deep ocean, where density variations are small. Direct measurement of the abyssal circulation is difficult because the region is dominated by eddies and turbulent motion. Thus, our understanding of the abyssal circulation is still incomplete.

To complement methods of physical oceanography, studies of the abyssal circulation also rely on the distribution of chemical tracers such as dissolved oxygen, biological nutrients (nitrate, phosphate, silicate), radioactive tracers (radiocarbon and tritium, an isotope of hydrogen), and chlorofluorocarbon compounds (CFCs). Traditionally, the distribution of these tracers is used to estimate the pathways of different water types in the abyss, because the chemicals tend to travel with the same water mass while they are circulating in the abyss.

The goal of our project is to determine to what extent measurements of two new members in the palette of marine tracers – a radioisotope of thorium (^{230}Th) and a radioisotope of protactinium (^{231}Pa) – provide quantitative information about the abyssal circulation. It is currently hypothesized that these tracers found in marine sediments provide insight into the circulation in the geological past. In order to assess this hypothesis, it is essential to understand what processes influence the distribution of both tracers in the ocean.

Thorium-230 and protactinium-231 are naturally occurring, produced from the radioactive decay of uranium isotopes. Because the distribution of uranium is approximately uniform throughout the ocean, the production of ^{230}Th and ^{231}Pa is also fairly uniform. Following their production, Th and Pa attach to particles that sink by gravity to the seafloor, where they become part of the sedimentary record.

Thorium and protactinium both stick to and unstick from ocean particles in a process called "reversible exchange." Current understanding suggests that, if this reversible exchange is stronger than the transport of these elements by the circulation, then the vertical distribution of these elements in the water column should be linear. Such linear distributions have been observed for Th in some oceanic regions (see figure, left).

The theory of reversible exchange also predicts that the time necessary to reach a linear distribution is a function of depth. At abyssal depths thorium would reach this distribution in a few decades, while protactinium would reach it in centuries. Thus, if the abyssal circulation 'renews' the deep waters at a rate faster than a few decades, the vertical distributions of Th and Pa will no longer be linear (example: figure, right). If it renews the deep waters at a rate faster than a few centuries but slower than a few decades, the distribution for thorium would be very close to linear, whereas the protactinium distribution would not.

The first step of our project was to compile an existing database of measurements of ^{230}Th and ^{231}Pa in the world oceans. Most known measurements of these isotopes are from the North Atlantic basin. The data showed that the observed vertical distributions of ^{230}Th and ^{231}Pa are typically non-linear, suggesting the effect of circulation. We are currently working on the interpretation of these data utilizing a statistical method ('inverse method'). In so doing, we will provide additional understanding about the abyssal circulation in the modern North Atlantic and help interpret the sedimentary records of ^{230}Th and ^{231}Pa in this basin. □

Ocean Carbon and Climate Change

Ocean Acidification

Scott C. Doney

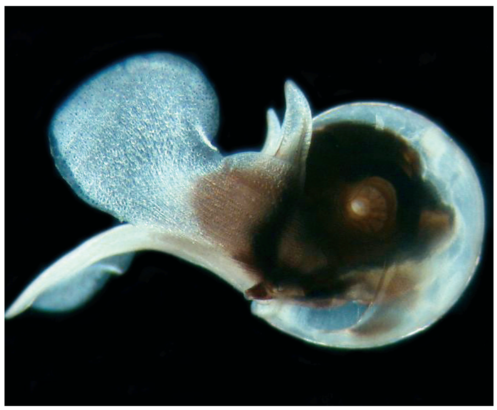
The modern world runs on fossil fuels, which, when burned, produce carbon dioxide. Much of this carbon dioxide ends up in the ocean. Since the combination of seawater and carbon dioxide forms a weak acid, this process is making the ocean more acidic, and new evidence suggests this may be harmful to marine life – from tiny floating plankton to huge coral reefs.

Since the late 1950s, scientists have been monitoring the levels of carbon dioxide in the atmosphere. Concentrations vary seasonally, but each year carbon dioxide levels have been higher than the year before. Atmospheric carbon dioxide levels in 2005 were about 30% higher than several centuries ago, and models predict that by the end of this century, the value will be two to three times pre-industrial levels.

Only 40% of the excess carbon dioxide stays in the atmosphere. The rest is taken up in equal amounts by the land and ocean. The amount the ocean takes up depends largely on the ocean circulation. When deep waters are brought up to the surface, they can absorb more carbon through air-sea gas exchange. The highest concentrations of anthropogenic carbon are found in ocean surface waters and in areas where surface waters sink, mostly in the polar regions.

Detecting and quantifying ocean carbon uptake, requires high quality field and analytical chemical methods. One approach is to measure the change in inorganic carbon concentrations over time by repeatedly taking measurements at the same spot in the ocean. One needs to sample the ocean over time periods of at least 5-10 years in order to see clear evidence of carbon uptake, because anthropogenic carbon builds up slowly and there is significant year-to-year natural variability. Last winter, a number of colleagues and I led a research expedition on the NOAA ship R/V *Ronald H. Brown* to the western South Atlantic to take such measurements.

Comparing our 2005 data to those obtained in 1989, we found that the upper few hundred meters of the ocean are now typically warmer and have more inorganic carbon and less dissolved oxygen than just a decade or two ago. Elevated inorganic carbon is even found in the deep ocean, brought there by waters sinking at the poles.



Limacina, a tiny swimming snail or pteropod, is common in Arctic and high latitude waters. Since it forms its shell from calcium carbonate, which can dissolve in an acidic environment, it is threatened by the increasing acidification of the oceans. Photo by Larry Madin.

Higher temperatures and lower oxygen may reflect greenhouse warming, while higher carbon concentrations are likely the result of the ocean absorbing carbon dioxide from the atmosphere. Similar trends are noted in the Pacific and Indian Oceans, and the field data are broadly consistent with predictions from computer simulations. But what do the higher carbon dioxide levels mean for the marine environment?

Many marine plants and animals build shells out of calcium carbonate from seawater. The concern is that, as pH drops, so too will the ability of these organisms to make shells and grow. Some of the most abundant organisms that make calcium carbonate shells are microscopic phytoplankton called coccolithophorids, which are covered in small calcium carbonate plates called coccoliths. Other important open-ocean calcifiers are the planktonic animals, foraminifera, related to amoeba, and pteropods, small marine mollusks. These calcifying plants and animals constitute a major food source for higher-level marine fish and mammals, including some species of whales.

At the other end of the size spectrum are corals. Coral polyps are actually small animals related to sea anemones that feed by filtering plankton out of the water. They secrete calcium carbonate skeletons that build up layer by layer over time, and the skeletons accumulate to form coral reefs. These reefs are the basis for some of the most productive and biologically diverse ecosystems of the world oceans.

The beautiful colors of corals are due to tiny algae that live inside the coral polyps as symbionts. During coral bleaching events, in response to environmental stress (e.g., warming or perhaps acidification), the algae leave the coral cells, exposing the white calcium carbonate skeleton underneath.

The Great Barrier Reef off Australia, the largest biological structure in the world, is simply the accumulation from generation after generation of corals and coralline algae. There are also recently discovered coldwater coral communities that live on continental margins and seamounts and form important deepwater fish habitats.

Our research shows that high latitude and deep-water ecosystems may be the first to show the effects of ocean acidification. Pteropods, polar mollusks that are a key prey species at the base of the food chain, may simply disappear or they may be forced to migrate to lower, warmer latitudes, because the acidic seawater will be lacking in aragonite, the primary component of their shells.

(continued)

Carbon and Climate Change (continued)

Photo courtesy of Andre Friewald

These species of corals, *Lophelia pertusa* (left) and *Paragorgia* (right), are cold and deep water corals that sustain numerous other marine animals off Georges Bank and in the North Atlantic. These corals live along the path of carbon-dioxide-rich waters, making them vulnerable to the ravages of an acidic ocean.

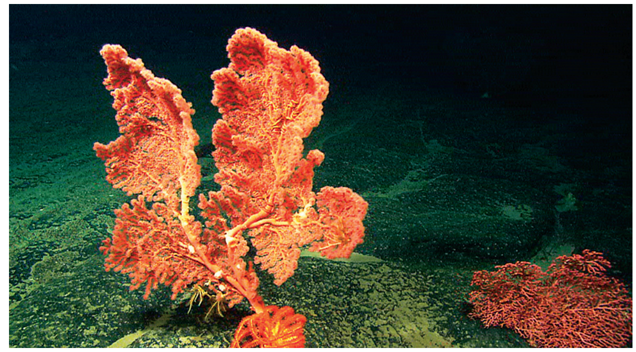


Photo courtesy of Deep Atlantic Stepping Stones

The high latitude calcifying phytoplankton and zooplankton may share a similar fate, though it may be delayed several decades because their shells are formed from the less soluble calcite. Deep coral communities will also be susceptible, particularly those in the western North Atlantic – along the path of water with high anthropogenic carbon.

The outlook for coral reefs is bleak. Ocean acidification is only one of a number of environmental and human stresses that include greenhouse warming, pollution, overfishing, and habitat destruction. Many reef ecosystems are already in steep decline. Episodes of coral bleaching are becoming more frequent, and ocean acidification may push many coral reefs over the edge.

Atmospheric carbon dioxide has varied significantly over the geological past, and there have been long periods, such as in the climatic warm epochs of the Cretaceous, when CO_2 levels were much higher than today. There have even been striking geological events when it appears that, due to natural processes, atmospheric CO_2 increased sharply, and there were large die-offs of marine organisms. We can use this information in the geological record as a guide to how ocean ecosystems may respond in the future.

The concern of many scientists, however, is that the current human-induced ocean acidification is occurring tens to hundreds of times more rapidly than in the past. Many plants and animals will not be able to adapt to these changes. Although not as easy to see as the consequences on land, we are dramatically altering the marine environment – and often not for the better. □

Friends of OCCI

A Salute to Gary Comer

Photo courtesy of Gary Comer

OCCI is deeply indebted to Gary Comer, philanthropist, avid sailor, explorer, and founder of the Lands' End clothing-catalogue company.

Mr. Comer has a deep interest in climate change, owing in part to a 2001 transit through the Northwest Passage, where he was alarmed by the lack of sea ice. Upon his return to the lower 48 states, Mr. Comer was determined to find out what was happening to the Arctic and the global climate. Over the past four years, he has funded basic research in climate change across the US and Europe. WHOI has been the beneficiary, via the Comer Science and Education Foundation, of a one million dollar grant to OCCI for climate change research and a five million dollar discretionary grant, also being allocated primarily to the OCCI. □

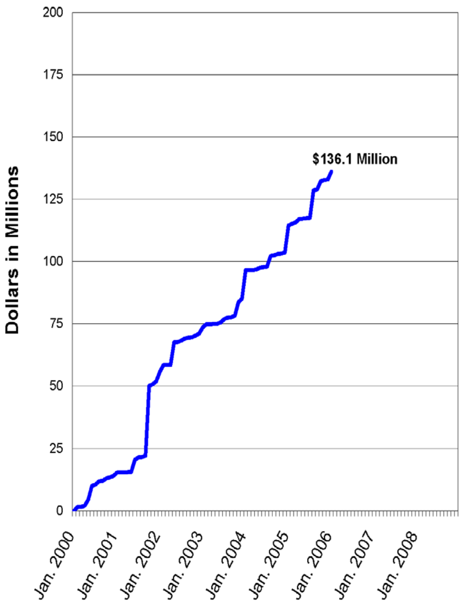
We appreciate the interest and support of donors, who are essential in providing us with an opportunity to further advance our knowledge of the ocean's role in climate change, to become more innovative and creative in our research, and to enable us to better communicate the results of our work to the public and to policy makers.

In addition to Mr. Comer, other donors who have contributed specifically to the OCCI include: The Cecil and Ida Green Foundation, Mr. and Mrs. James E. Moltz (who sponsor fellows in each Ocean Institute), Mr. and Mrs. Frank W. Hoch, Dr. and Mrs. John J. Wise, Mr. and Mrs. Robert F. Hoerle, Mr. and Mrs. Robert M. Raiff, Mr. and Mrs. Steven G. Hoch, Dr. Thomas Keffer and Ms. Lee Christie, Ms. Robin L. Kaiser and Mr. Peter A. Gish, and the Willis Lease Finance Corporation. Our sincerest thanks to all.

- Terry Joyce □

Financial Information

Campaign Funds Raised to Date
$136,054,700
As of December 31, 2005



Allocation of OCCI Funds

Between 2001 and 2005, investment in the work of OCCI totaled $5,631,115. The vast majority of this funding was allocated for research projects (77%). Forty-eight scientific and technical staff members at WHOI benefited, as they participated in 38 individual projects. All WHOI departments were represented, with the majority of grants going to investigators in the Physical Oceanography and Geology & Geophysics departments. In addition, the OCCI budget supported eight fellows (13%), four postdoctoral scholars (4%), and two graduate students (3%). Discretionary spending represented one percent of OCCI expenditures, while two percent aided communications and outreach: forums, seminars, conferences and workshops. Significant work has been accomplished through the OCCI, and we are deeply indebted to all who have contributed their financial support to the Ocean Institutes and to the Institution in general. □

Campaign Progress

"Depth of Leadership," the WHOI campaign to advance a new scientific agenda for oceanography, was made public in 2005. During that year, WHOI received its second largest gift to date, a $14.5 million bequest from Claudia S. Heyman. Ms. Heyman was a 35 year-old native of Tulsa, Oklahoma, living in Boston at the time of her death. She had visited the Institution only briefly and had minimal contact with our staff, yet her remarkable gift will have a lasting effect on the Institution.

Ms. Heyman will be remembered by the establishment of four fellowships named in her honor, one in each of the four Ocean Institutes. This gift, along with thousands of others from our friends and supporters brought our campaign total to over $136 million by year's end. Thank you! □

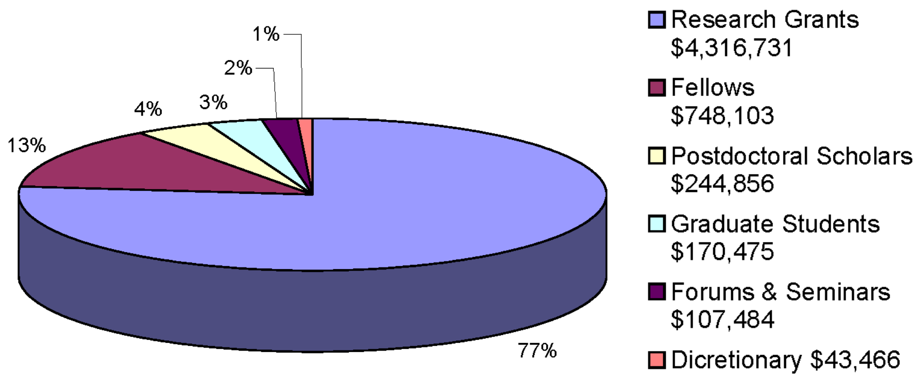
Claudia Heyman

OCCI Leveraging

A number of our past internally-funded projects have been successful in leveraging federal funds to continue and/or expand the work. For example, "Station W" (launched with Vetlesen Foundation funds through the OCCI) has become "Line W," with support for additional moorings and ship time in a 5-year $3.7M NSF grant to co-PIs, Terry Joyce, John Toole, Ruth Curry and Bob Pickart. Their study of the Deep Western Boundary Current south of New England explores the relationship of deep water flow to upper ocean circulation. Other examples include the research of Andrey Proshutinsky and Rick Krishfield, who received OCCI funding to maintain a long-term observing system in the Beaufort Gyre, the major reservoir of relatively fresh water in the Arctic. This project continues with a grant of $2.85 million from NSF's Office of Polar Programs.

Additionally, Scott Doney and colleagues were awarded $1.8 million from NASA for a study of carbon dioxide exchange between the ocean and atmosphere for the North American Carbon Project. Anne Cohen and Michael McCartney received $332K from NSF to study 275 years of past sea surface temperatures with data obtained from a brain coral skeleton. And Jerry McManus was awarded a $504K grant from NSF to investigate climate-related changes over the past ten thousand years. □

OCCI Fund Allocation 2001 - 2005



$5,631,115